FINAL REPORT

to

Office of Naval Research

Contract No. N00014-84-C-0618

entitled

STUDIES OF VORTEX INTERACTIONS

1 August 1984 - 31 December 1989

Anatol Roshko

Anatol Roshko
Theodore von Kármán
Professor of Aeronautics

Graduate Aeronautical Laboratories
California Institute of Technology
Pasadena, California 91125

June 26, 1990

Research work accomplished under this contract/grant includes the following:

1) X-Y Tow Tank Facility. This facility was designed and constructed. for use in the research described in 3. below. It consists of a tank 15 ft (4.6 m) long, 3.5 ft (1.1 m) wide and 3.5 ft deep with glass sides and bottom providing unobstructed views of the interior from all sides. A carriage riding on rails over the top of the tank supports a second carriage which moves at right angles to the first. The latter carries the experimental body which can thus be traversed on steady or unsteady trajectories in the horizontal (X-) plane. The carriages are cable driven by motors which are computer controlled.

2. Experimental Techniques developed for flow visualisation in the Tow Tank included improvements in laser-induced fluorescence and particle-streakline techniques.

3. Research Accomplishments are described in detail in the on page two. Highlights are summarized here:

- It was found, for an oscillating body, ~~that~~ it is the acceleration phase of the body's motion in each half cycle that synchronises the vortex formation, and thereby influences both the magnitude and phase of the forces on the body (which are of central importance to flow-induced vibration).
- It was demonstrated ~~for the~~ first time how flows with truly two-dimensional parallel shedding can be achieved, which can now be directly compared with the many 2-D numerical simulations presently being carried out.
- It was shown that the transition to three-dimensionality in the cylinder wake involves two stages, each of which is associated with a discontinuous change in the mode of vortex formation (corresponding with different scales of streamwise vorticity). The second discontinuity is particularly interesting as it involves a competition between two modes.
- It was found that vortex dislocations, which appear when sections of a cylinder span shed vortices out of phase with neighboring sections, are fundamental features of both the laminar and 3-D transitional cylinder wakes. The resulting large-scale Λ-structures have also been forced to occur, and have been found to have distinct similarities with turbulent spots in a boundary layer.
- It was shown that the variation of base pressure coefficient with Reynolds number shows a remarkably good correspondence with the variation of the Strouhal number, at low Reynolds numbers. It is also possible to relate the variation in base pressure with the physical modes of wake formation found in previous studies.

PUBLICATIONS IN REFEREED JOURNALS

1. C.H.K. Williamson and A. Roshko (1988) Vortex formation in the wake of an oscillating cylinder. Journal of Fluids and Structures, **2**, 355-381.
2. C.H.K. Williamson (1988) Defining a universal and continuous Strouhal-Reynolds number relationship for the laminar vortex shedding of a circular cylinder. Physics of Fluids, **31** 2742-2745.
3. C.H.K. Williamson (1988) The existence of two stages in the transition to three-dimensionality of a cylinder wake. Physics of Fluids, **31**, 3165-3168.
4. C.H.K. Williamson (1989) Generation of periodic vortex dislocations due to a point disturbance in a planar wake. In the Gallery of Fluid Motion, Physics of Fluids, **A1**,1444. (September 1989).
5. C.H.K.Williamson (1989) Oblique and parallel modes of vortex shedding in the wake of a cylinder. Journal of Fluid Mechanics, **206**, 579-628.
6. C.H.K. Williamson (1990) Formation of vortex pairs from an oscillating cylinder. In the Gallery of Fluid Motion, Physics of Fluids, **A2**. (September 1990).
7. C.H.K. Williamson and A. Roshko (1990) Measurements of the base pressure of a cylinder at low Reynolds numbers. Zeitschrift für Flugwissensschaften und Weltraumforschung, **14**, 38-46.

OTHER REPORTS

1. C.H.K. Williamson and A. Roshko (1986) Vortex dynamics in the wake of an oscillating Cylinder. Bull. American Physical Society, **31**, 1690.
2. C.H.K. Williamson and A. Roshko (1986) Studies of vortex interactions. Proceedings of the Symposium for the Fortieth Anniversary of the Office of Naval Research, Washington, D.C.
3. A. Roshko (1986) (Co-editor) AGARD Symposium on aerodynamic and related hydrodynamic studies using water facilities, Monterey, California.
4. A. Roshko (1987) O.N.R. Prize Lecture: Turbulent shear flows: a case study, Bull. American Physical Society, **32**, 2036.
5. A. Roshko (1987) Unsteady and separated flows. Workshop on Unsteady Separated Flows, U.S.A.F. Academy, Colorado Springs.
6. C.H.K. Williamson (1987) Three-dimensional transition in the near wake of a circular cylinder. Bull. American Physical Society, **32**, 2098.
7. C.H.K. Williamson (1988) Defining a universal and continuous Strouhal-Reynolds number relationship for the laminar vortex shedding of a circular cylinder. Bull. American Physical Society, **33**, 2245.